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A proposed approach for the assimilation of cloudy infrared radiances: impact study based on AIRS simulations

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Environment Canada Environnement Canada

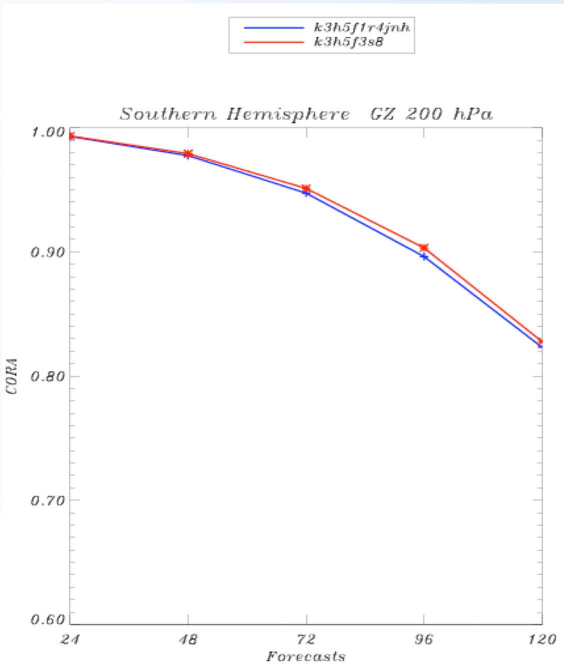
Canada

AIRS assimilation at EC

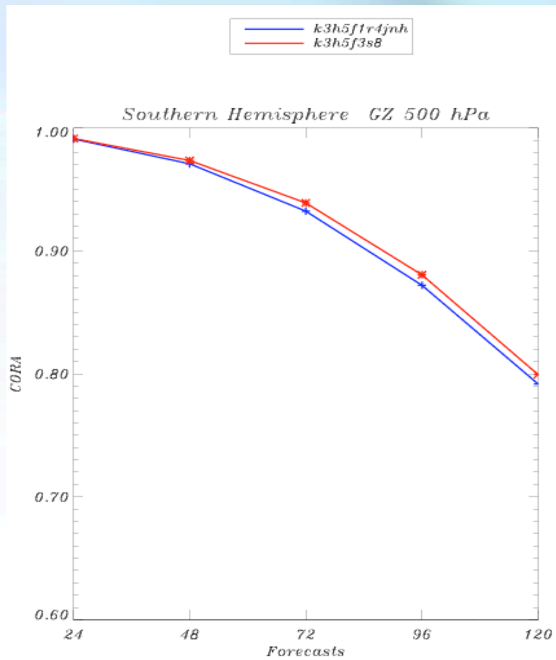
- Current status: 87 channels to be assimilated operationally in fall 2007. RTTOV-8 RTM. Thinning : 250 km. About 90,000 radiances per 6h. Dynamic bias correction. Model top 10 hPa, 58 levels.
- ~125 channels planned for fall 2008 with model top at 0.1 hPa, 80 levels.
- Active research on cloudy radiance assimilation

GZ anomaly correlations AIRS-NOAIRS

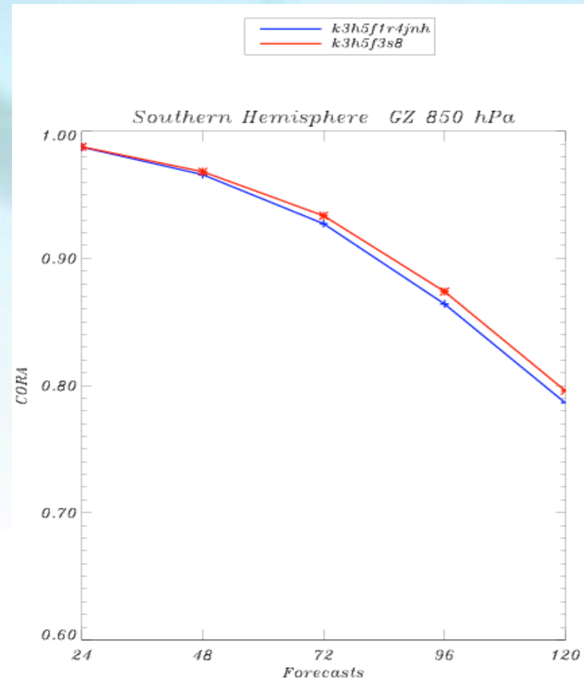
200 hPa



500 hPa

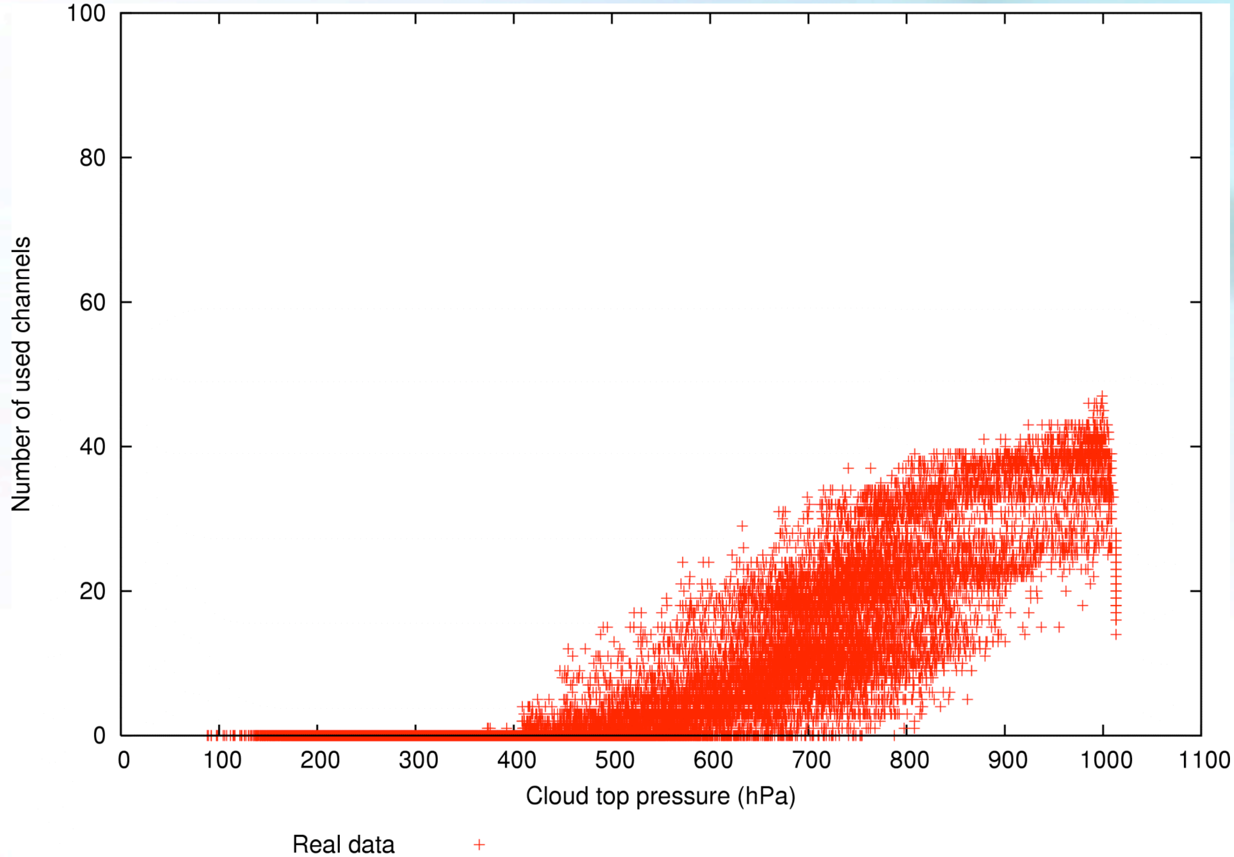


850 hPa



SH, 35 days, winter 2005-2006, 3D-FGAT. AMSU-A from AQUA assimilated
In both cycles.

Cloud affected radiances: a severe limitation



Clear skies: all 100 channels used at night

Less in daytime

Low clouds: max of 45 channels used

Cloud top above 400 hPa: no AIRS channels are assimilated in our system due to broad response functions

Example based on real data with 100 channels considered

Simplified approach to cloudy radiance modeling and assimilation

- Approach chosen: cloudy radiance computed assuming a single-layer cloud defined by an effective height P_c and emissivity $N\varepsilon(\nu)$:

$$I_{cld}(\nu) = N\varepsilon(\nu)\, I \quad (\nu) + (1 - N\varepsilon(\nu)) \quad (\nu)$$

- Not oversimplified however: cloud emissivity to depend on wavelength and phase. Mixed phase considered. RTM and TL/AD modified accordingly.

Cloud emissivity model

$$N\mathring{a}(\nu) = 1 - \exp\left[-k_{cld}(\acute{\imath})\delta \;\right]$$

δ: effective cloud water path (= secθ ΔP g^{-1} CWC)
k_{cld} cloud effective absorption coefficient accounting approximately for scattering following Chou et al. 1999 :

$$k_{cld}(\acute{\imath}) = k_{ext}(\acute{\imath})\left[\left(1 - \grave{u}(\acute{\imath})\right) + b(\acute{\imath})\grave{u}(\acute{\imath})\right]$$

With ω the single scattering albedo, k_{ext} the extinction coefficient and b the backscattered fraction :

$$b = \frac{1}{2}\int_0^1 d\mu \int_{-1}^0 \overline{P}(\mu, \mu')d\mu'.$$

Cloud emissivity model: mixed phase

- Liquid cloud optical properties from Lindner and Li (2000) parameterization as a function of the effective radius r_e (for k_{ext}, ω, g).
- Ice cloud optical properties from Baran et al. (2004, 2002 and 2005 private communication) for hexagonal column ice crystals as a function of the effective diameter D_e.

Optical properties are combined given the liquid fraction f_w from Rockel et al. (1991)

$$f_w = \begin{cases} 0.0059 + 0.9941 \exp\left[-0.003102(T_c - 273.16)^2\right]; & T_c < 273.16 \\ 1.0 \; ; & T_c > 273.16 \end{cases}$$

$$k_{ext} = f_w k_{ext}^w + (1 - f_w) k_{ext}^i \qquad ù = \frac{f_w k_{ext}^w ù^w + (1 - f_w) k_{ext}^i ù^i}{f_w k_{ext}^w + (1 - f_w) k_{ext}^i}$$

$$b = F(g) \approx \frac{1-g}{2} \quad \text{with} \quad g = \frac{f_w k_{ext}^w ù^w g^w + (1 - f_w) k_{ext}^i ù^i g^i}{f_w k_{ext}^w ù^w + (1 - f_w) k_{ext}^i ù^i}$$

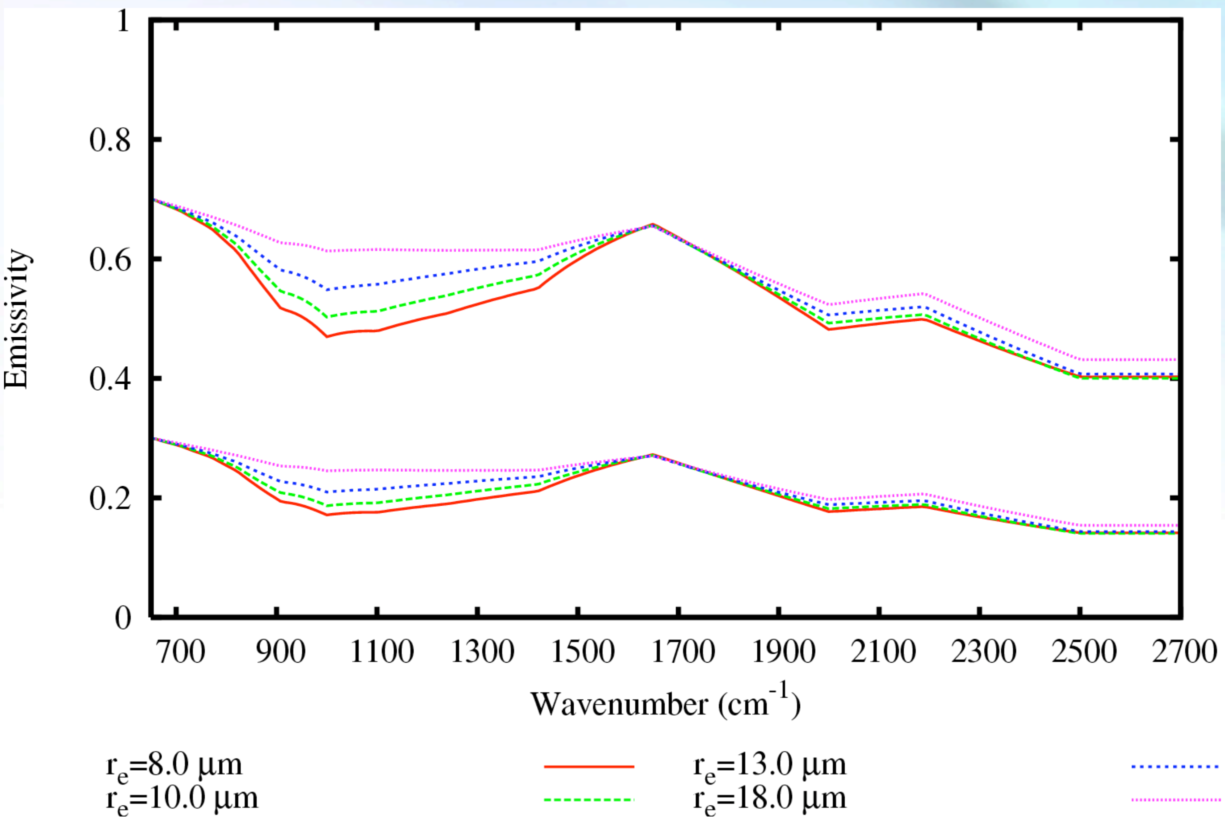
All parameterizations easily differenciable for AD/TL/K RTM

Cloud emissivity model: summary

- To summarize a full cloudy radiance spectrum can be simulated using only 4 cloud parameters, independent of wavelength:
  - The cloud top pressure $\mathbf{P_c}$ (gives also the cloud temperature T_c)
  - The effective cloud water path $\boldsymbol{\delta}$
  - The cloud effective radius $\mathbf{r_e}$ (liquid phase)
  - The cloud effective diameter $\mathbf{D_e}$ (ice phase)
- Dependence of emissivity and waveleght, phase via modeling

Examples of cloud emissivity spectra

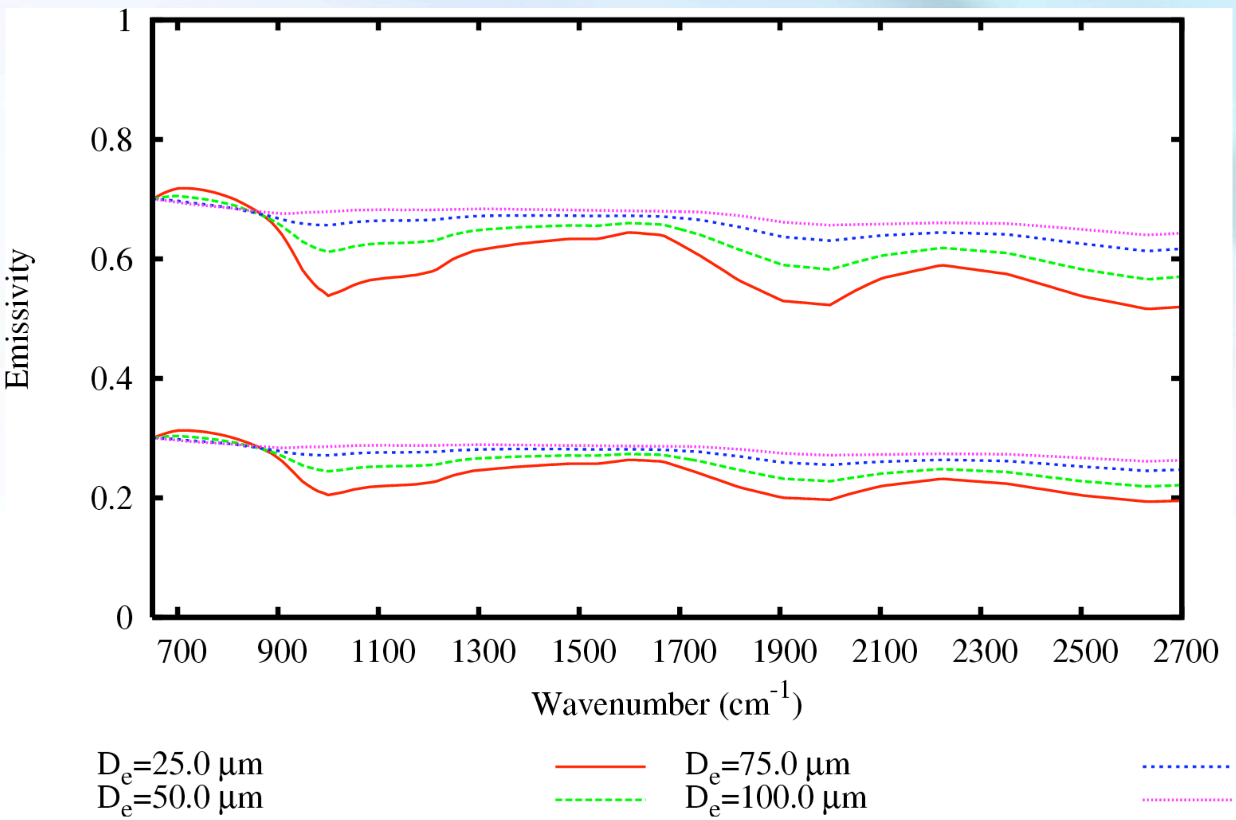
Liquid Water cloud: 15 μ emissivity set to 0.7 or 0.3 (δ fixed)



Note: AIRS gap 1614-2181 cm^{-1}

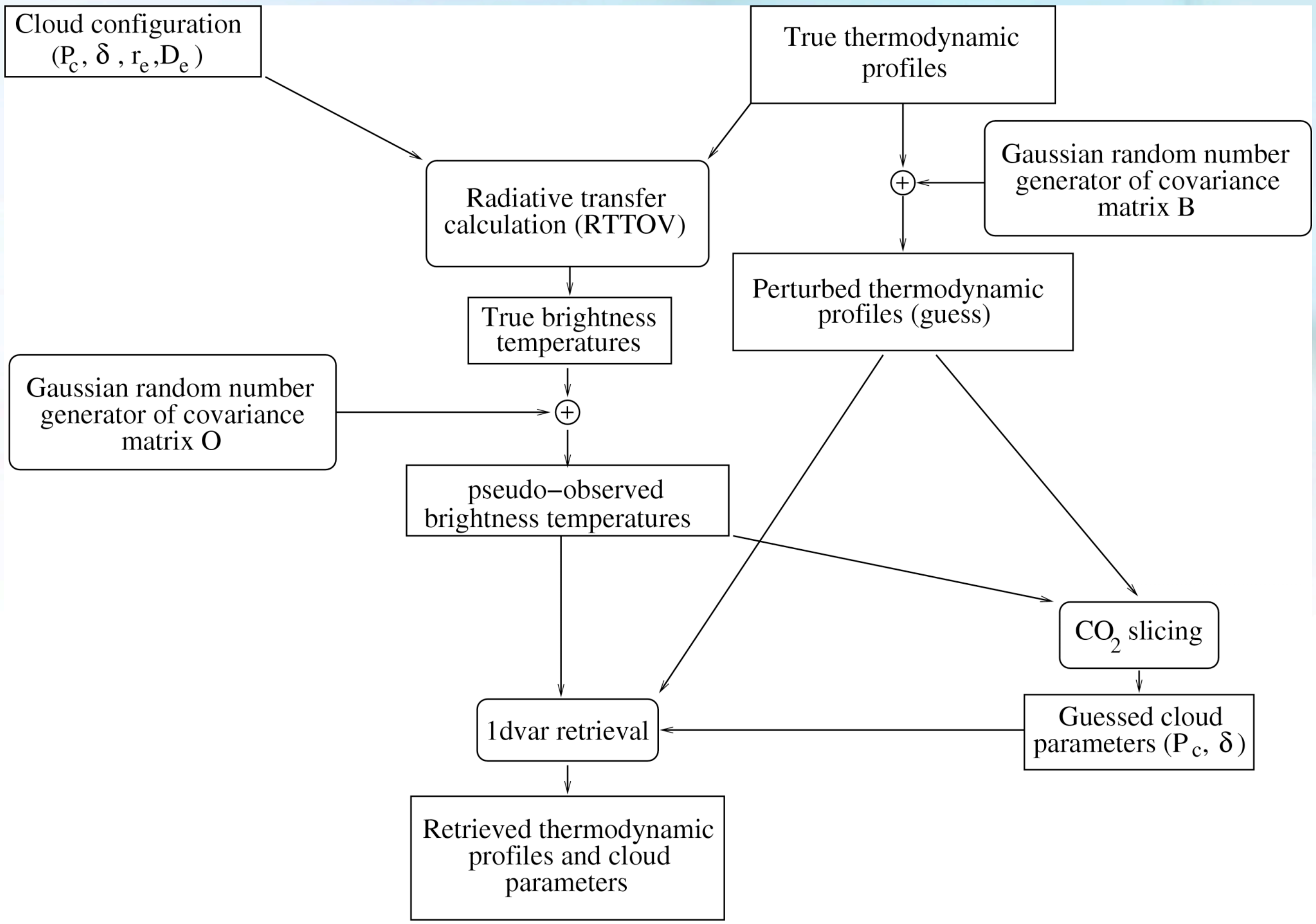
Examples of cloud emissivity spectra

Ice Water cloud 15 μ emissivity set to 0.7 or 0.3 (δ fixed)



Note: AIRS gap
1614-2181 cm-1

Principle of the Monte-Carlo experiments



Each cloud configuration perturbed 1000 times

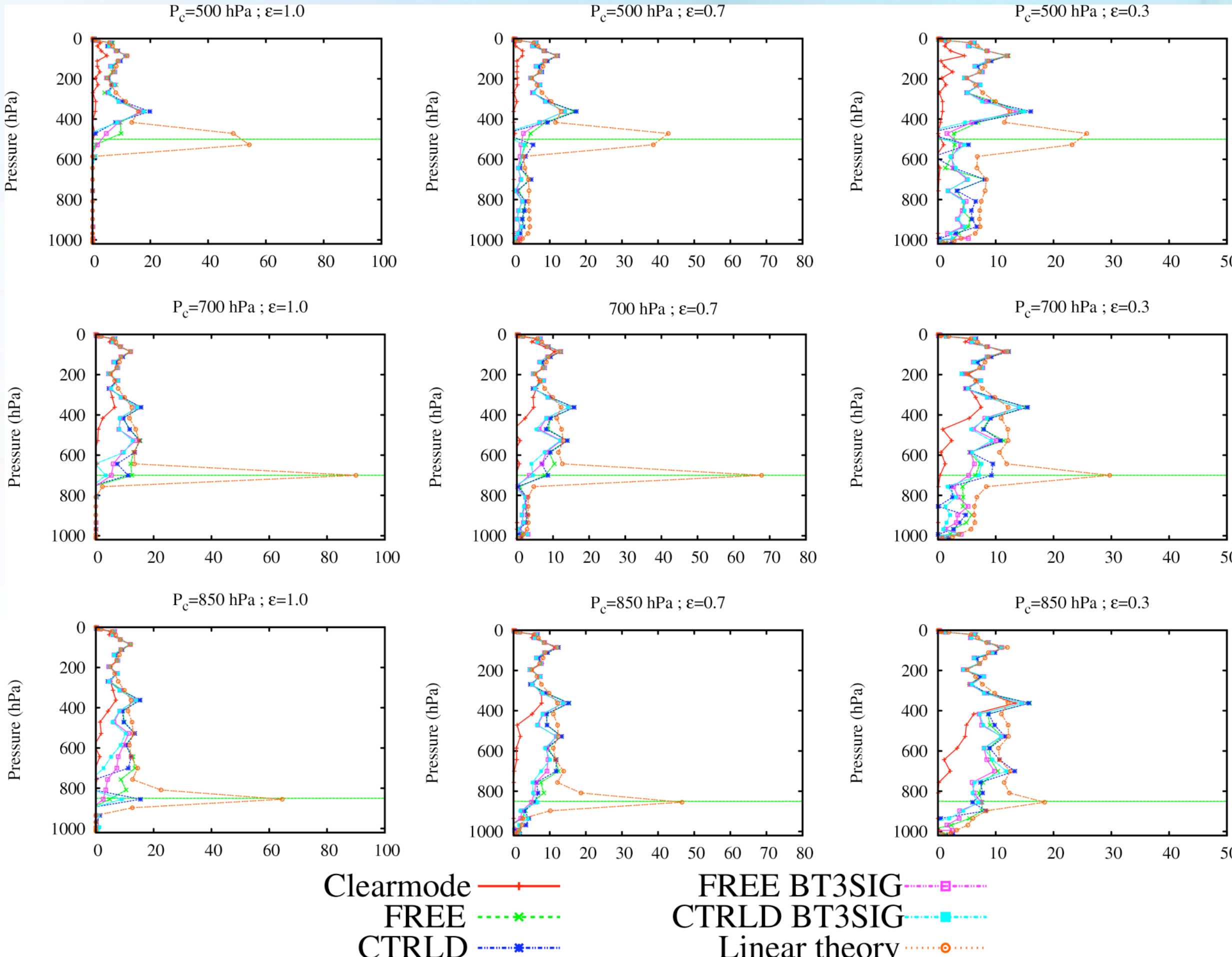
Monte-Carlo experiments: definitions

- The 1D-var experiments were performed with various background constraints or conditions:
  - CLR : using only channels insensitive to cloud
  - FREE: using all channels with free cloud parameters
  - CTRLD: using all channels with constrained cloud parameters
  - FXD: using all channels with fixed cloud parameters
  - BT3SIG: one of the above using only channels for which the background departure (O-P) is lower than 3 times the standard deviation of <O-P> for the 1000 cases
- Nine cloud configurations: Pc = 850, 500, 500 hPa and 15 micron emissivity = 0.3, 0.7, 1.0.

Monte-Carlo experiments: outputs

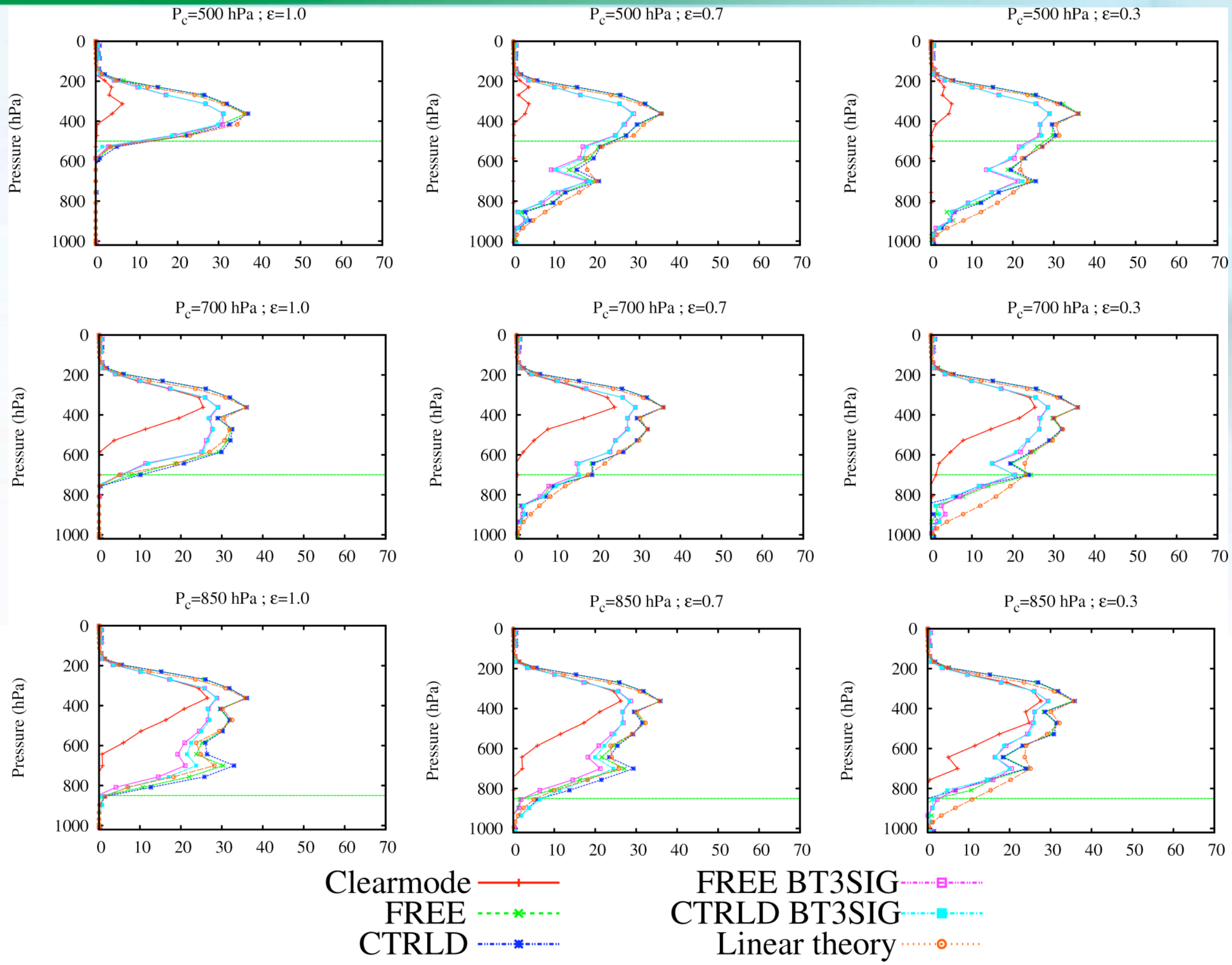
- Statistics calculated for 1000 realizations for each of the 9 cloud configurations :
  - Bias : $\mathbf{b} = \langle \mathbf{x}_t - \mathbf{x}_a \rangle$
  - Analyzed covariance $\mathbf{A}_{ij} = \langle (\mathbf{x_{ti}} - \mathbf{x_{ai}} - \mathbf{b_i})(\mathbf{x_{tj}} - \mathbf{x_{aj}} - \mathbf{b_j}) \rangle$
  - Variance reduction $\mathbf{V_r} = diag(\mathbf{I} - \mathbf{AB}^{-1})$
  - Degrees of freedom for signal $DFS = Trace(\mathbf{I} - \mathbf{AB}^{-1})$

Variance Reduction for temperature profiles



Reduction slightly less for BT3SIG due to less channels

Variance reduction for water vapor profiles



Temperature degrees of freedom for signal (DFS) for the CLR, FREE and FREE BT3SIG experiments.

	P_c=850 hPa	P_c=700 hPa	P_c=500 hPa
ε(15μm)=1.0	*0.904 / 1.871 / 1.519*	*0.847 / 1.682 / 1.439*	*0.232 / 1.162 / 1.106*
ε(15μm)=0.7	*0.949 / 1.875 / 1.692*	*0.762 / 1.693 / 1.493*	*0.119 / 1.389 / 1.193*
ε(15μm)=0.3	*1.151 / 1.810 / 1.705*	*0.938 / 1.738 / 1.590*	*0.185 / 1.496 / 1.380*

Temperature profile DFS for clear sky case using all (100) channels: 2.299

Logarithm of water vapour mixing ratio degrees of freedom for signal (DFS) for the CLR, FREE and FREE BT3SIG experiments.

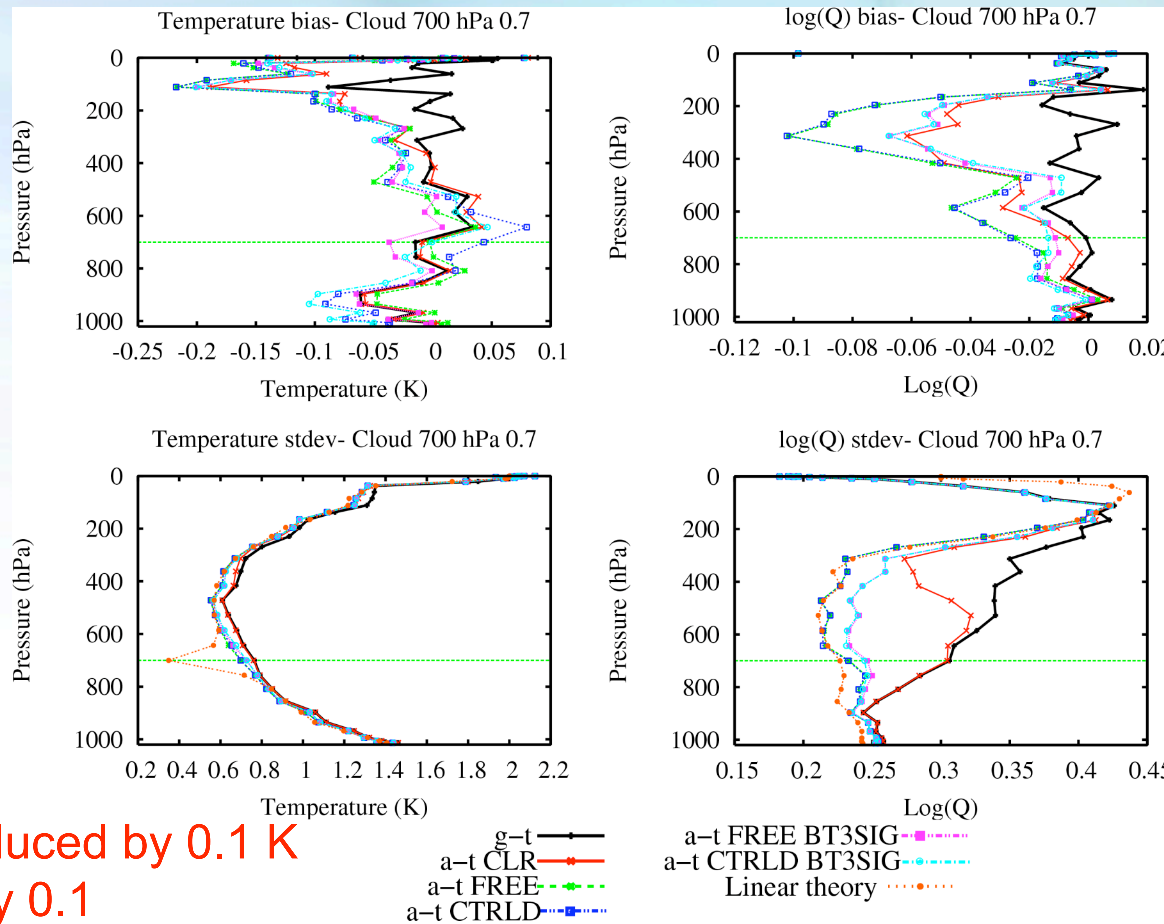
	P_c=850 hPa	P_c=700 hPa	P_c=500 hPa
ε(15µm)=1.0	*1.378 / 3.190 / 2.425*	*1.158 / 2.643 / 2.080*	*0.209 / 1.733 / 1.414*
ε(15µm)=0.7	*1.433 / 3.081 / 2.482*	*1.060 / 2.882 / 2.349*	*0.146 / 2.767 / 2.225*
ε(15µm)=0.3	*1.778 / 2.986 / 2.475*	*1.339 / 3.012 / 2.483*	*0.187 / 3.075 / 2.522*

Log(q) profile DFS for clear sky case using all (100) channels: 3.427

Detailed analysis of the (700 ; 0.7) configuration

Bias

Standard deviation



Std (Temp) reduced by 0.1 K
and std ln(q) by 0.1
Ln(q) biases reduced in BT3SIG

Note: tropical error background stats

Cloud parameter retrieval statistics

P_c STDDEV (hPa) before/after assimilation

	Pc=850 hPa	***Pc=700 hPa***	***Pc=500 hPa***
e(15mm)=1.0	55.43 / 13.41	23.54 / 9.21	13.36 / 5.77
e(15mm)=0.7	63.96 / 31.55	50.63 / 18.38	30.38 / 10.82
e(15mm)=0.3	79.94 / 108.85	79.46 / 63.45	71.23 / 36.07

15 μm cloud emissivity STDDEV before/after assimilation

	Pc=850 hPa	***Pc=700 hPa***	***Pc=500 hPa***
e(15mm)=1.0	0.17 / 0.02	0.06 / 0.0001	0.032 / 0.00009
e(15mm)=0.7	0.19 / 0.12	0.13 / 0.05	0.070 / 0.024
e(15mm)=0.3	0.34 / 0.26	0.21 / 0.11	0.12 / 0.04

Large improvement from assimilation over CO_2 slicing guess
Problems with low clouds with low emissivity
Target is 35 hPa for P_c and 0.035 for emissivity

Sensitivity to size parameter (1)

- Climatological values are used as first guess for $\mathbf{r_e}$, $\mathbf{D_e}$. For $\boldsymbol{\delta}$ and $\mathbf{P_c}$ a first guess is obtained from CO_2 slicing.
- The size parameter is allow to vary in the assimilation. What is the impact of an error on the initial value ?
- Is there some skill in retrieving the size parameter?

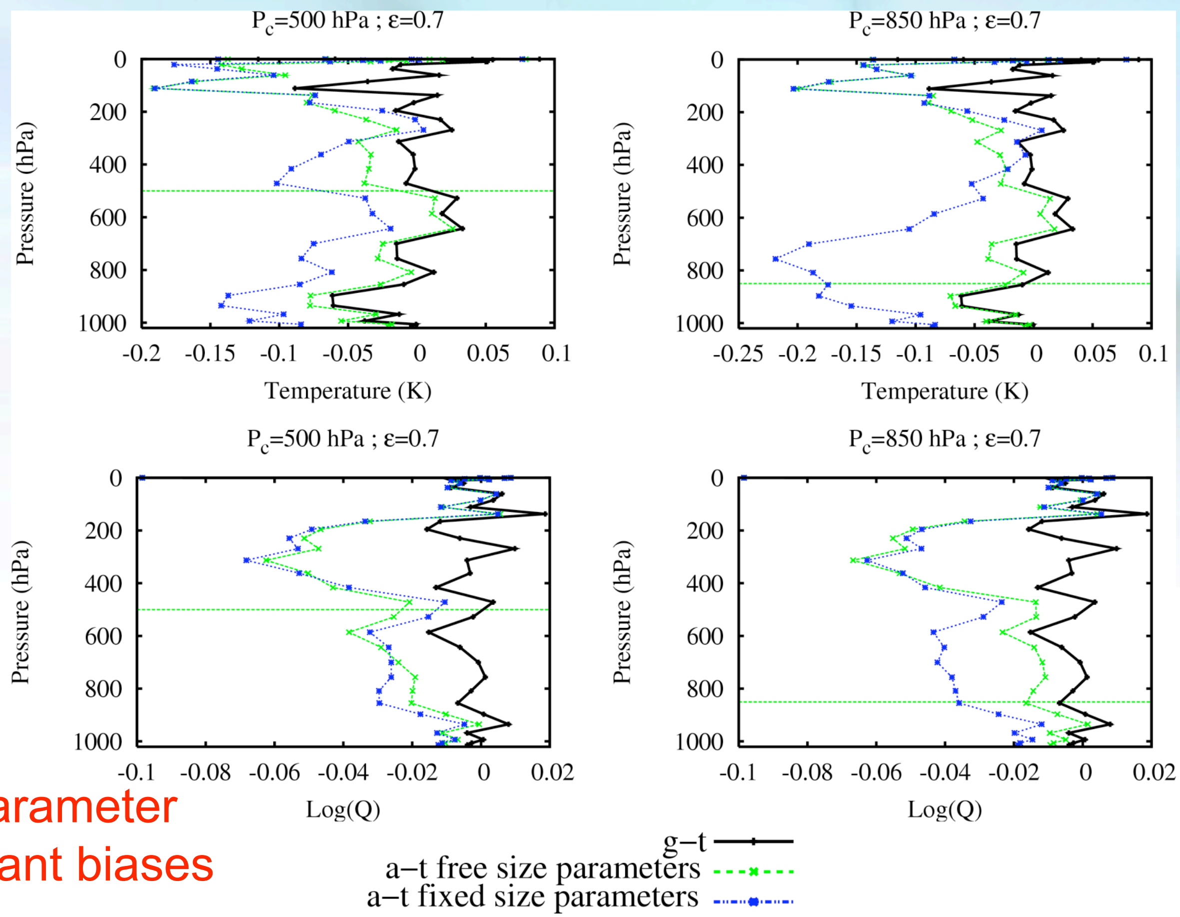
Sensitivity to particle size (2)

Assumed particle sizes :
- 8 µm for r_e (instead of 13)
- 50 µm for D_e (instead of 25)

Impact on biases

Ice cloud

water cloud



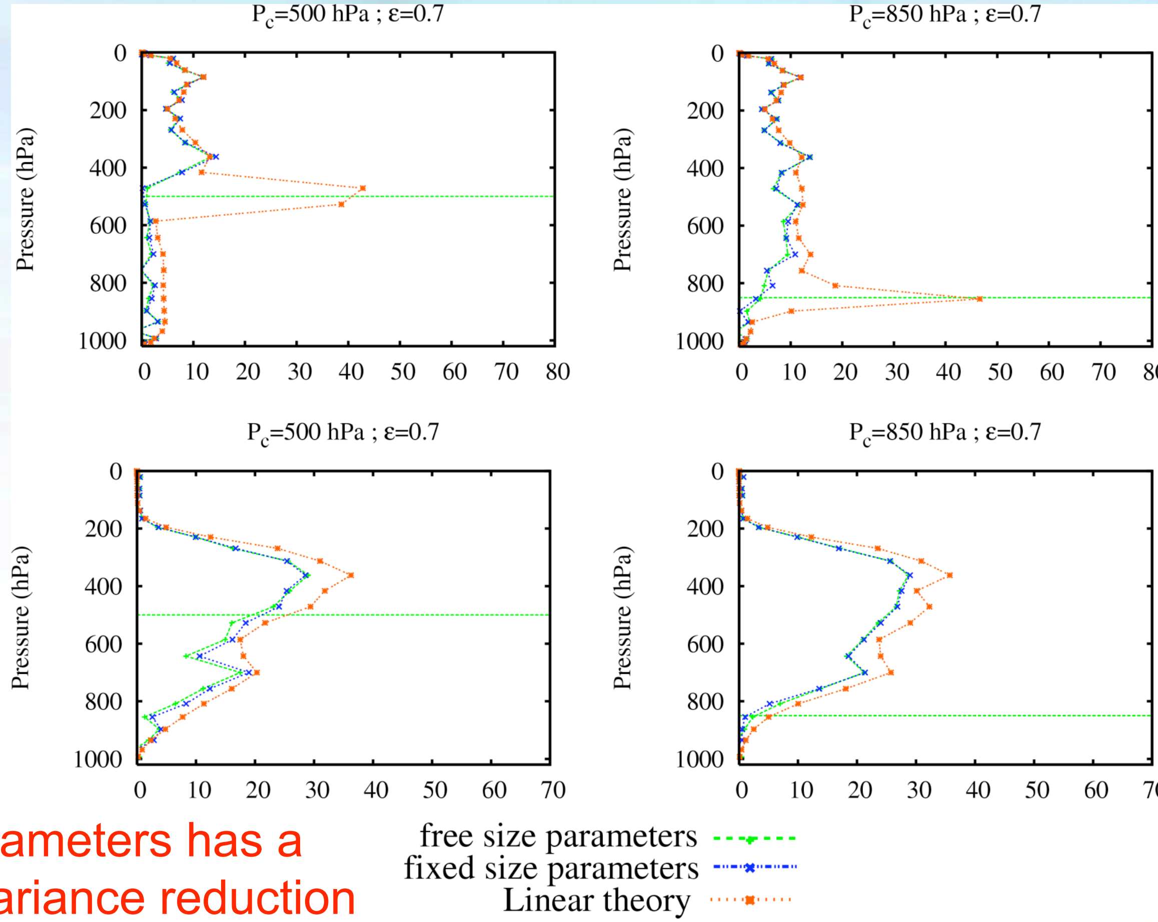
Fixing the size parameter
Results in significant biases

Sensitivity to particle size (3)

Variance reduction (Temp: top; ln(q): bottom)

Assumed particle sizes :
- 8 µm for r_e (instead of 13)
- 50 µm for D_e (instead of 25)

Impact on error variance reduction



Fixing the size parameters has a minor impact on variance reduction

Retrieving skill associated with D_e, R_e?

- From 1000 simulations:
- R_e: guess: 13 μm, true: 8 μm; P_c =850 Hpa,

  emi (15 μm = 0.7). The retrieved mean R_e was 9.3 μm (bias of 1.3 μm) and STD = 3.0 μm.

- D_e: guess: 25 μm, true 50 μm; P_c= 500 hPa

  emi (15 μm = 0.7. The retrieved mean D_e was 37.5 μm (bias of 12.5 μm) and STD = 8.1 μm.

Capability to retrieve effective particle size has some value, with rms errors in the 30-50 % range

Conclusions (1)

- Assimilation of cloudy radiances from AIRS has the potential to significantly improve NWP analyses of temperature and humidity
- Highest impact expected for mid-level scattered clouds situations in the layer just above the cloud. Some skill also noted below cloud level
- Better to let cloud parameters only weakly constrained to avoid biases in sounding retrievals
- Cloud parameters most difficult to infer for low clouds and low emissivity
- Cloudy assimilation expected to be most successful for cases where std (Pc) < 35 hPa and std (emi) < 0.035. Pre-determining such cases is a challenge.
- There is some skill in retrieving the cloud effective particle size: errors of the order of 30-50%.
- Using real data will no doubt create additional sources of uncertainty such as bias correction for cloudy radiances and the need to avoid problematic cases such as multi-layered fields-of-view.

Conclusions (2)

- The idea of predefining the cloud parameters in (e.g. via 1D-var) and to keep these fixed in 3D/4D assimilation is likely to lead to biases. It is preferable to use all available data together.
- Therefore, the operational assimilation code has been modified to include the *local* estimate of the 4 cloud parameters in the 4D-var minimization.
- First 3D/4D assimilation results with real data should be available soon.

Thank you!